Characterization of layered surface structures using EUV and soft X-ray radiation

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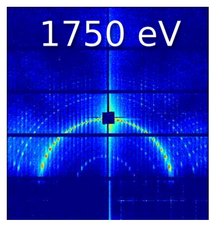
Introduction

EUV lithography requires sophisticated multilayer reflective coatings on optical elements and photo masks. These coatings must provide high EUV reflectance and robustness with respect the harsh environment of EUV lithography tools. PTB has developed unique measurement capabilities to characterize such layer systems based on its sound experience in synchrotron radiation based metrology. Besides measuring the EUV reflectance, the interference of the radiation with the multilayer coating can also be used as a means for depth sensitive chemical analysis using soft X-ray grazing incidence X-ray fluorescence spectroscopy. This method can be tailored to measure depth profiles within the multilayer stack as well as in the uppermost capping layers. In combination with electron detection, e.g. just measuring the total yield of emitted electrons instead of fluorescence photon detection, specifically the top surface can be characterized. Geometrical layer properties like e.g. surface and interface roughness can be inspected using EUV and X-ray scattering methods. These methods are also applicable to the non-destructive measurement of geometrical form parameters like width, height and side wall angles of absorber structures on EUV photo masks.

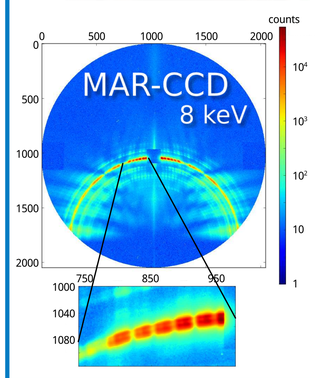
GISAXS

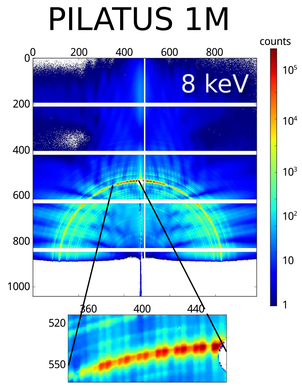
Grazing-incidence small-angle scattering

low energy accessible with new



PILATUS 1M



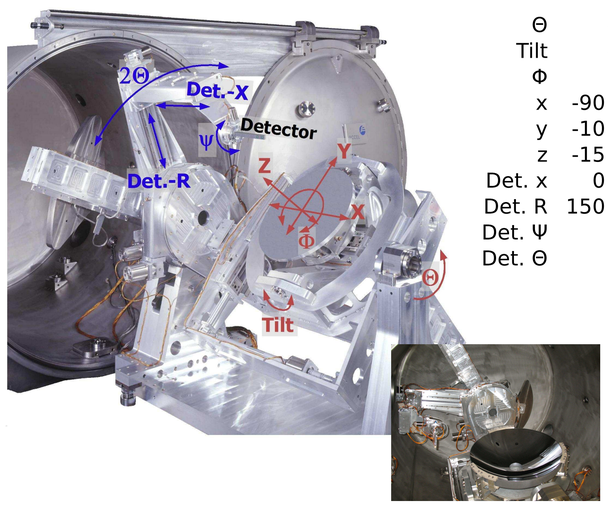


single photon counting (1MHz)

delta like point spread function (PSF)

[1]

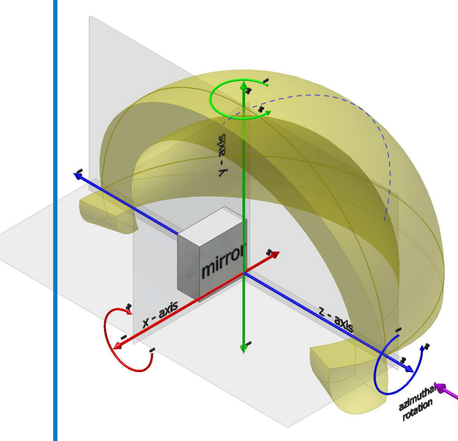
EUV Reflectometer



Θ	-30° to 95°
Tilt	-10° to 10°
Φ	0° to 360°
x	-90 mm to 90 mm
y	-10 mm to 300 mm
z	-15 mm to 140 mm
Det. x	0 mm to 120 mm
Det. R	150 mm to 550 mm
Det. Ψ	0° to 180°
Det. Θ	-5° to 190°

Accuracy
10µm or 0.01°

New Scatterometer (4Q/2012)



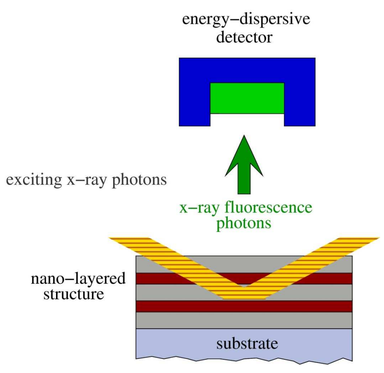
- UHV (10^{-9} mbar)
  In-situ sample transfer
- Sample: (190 x 190 x 70) mm^3
  5 kg
- quarter-sphere 2Θ (yellow)

Θ: -30° to 100°
phi: -30° to 100° } repro: 0.001°
rho: -179° to 179°

x: 100 mm
y: 100 mm } repro: 1 µm
z: 25 mm

GIXRF

Grazing incidence X-ray fluorescence analysis



Analysis of nano-layered structures

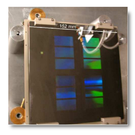
Elemental depth profiling

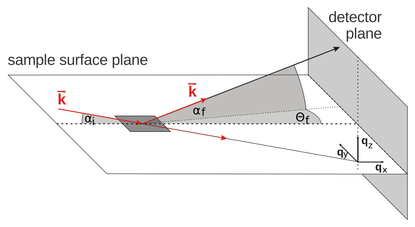
Penetration depth tunable from few to several hundreds of nanometers when modifying the X-ray Standing Wave field

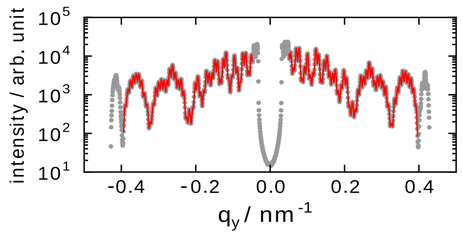
Combining with high-resolution absorption spectroscopy
➔ Chemical bonds

Direct structural characterisation of line gratings with GISAXS

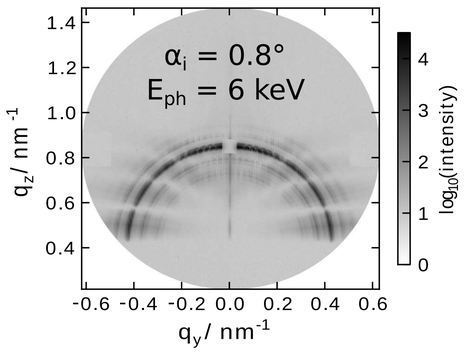
IOF JENA
12 different gratings



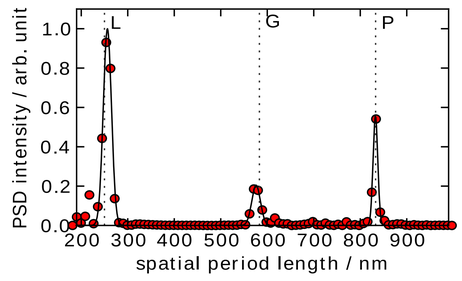




Extracted profile along the Ewald semicircle.



kinematical approximation



Groovewidth /nm
exp. 583(16)
nom. 583

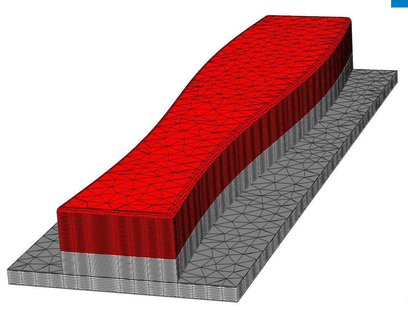
Linewidths /nm
exp. 249(16)
nom. 250

[2]

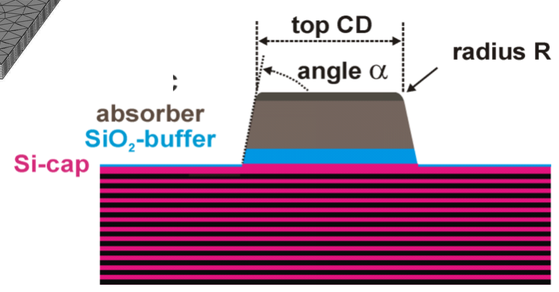
Simulation of rough gratings

JCMwave
JCMsuite
FEM Maxwell-solver

Diffractionpattern
100 nm grating
200 nm period
10 nm LER Amplitude



unit-cell with sinusoidal LWR

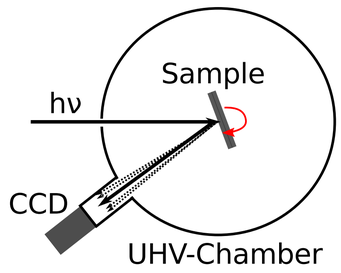


...disturbed diffraction intensities can be estimated using the numerical result of an undisturbed grating, and the results of the Fraunhofer model without explicitly simulating the line roughness by FEM

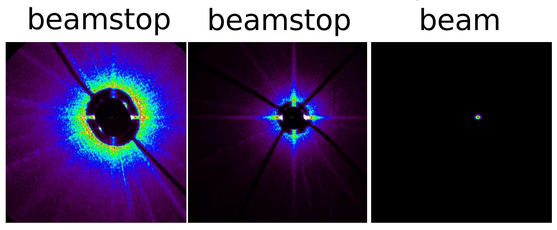
$$I_f(k_x, \frac{2\pi m}{d_r}) = J_m^2(ak_x) \times I_r(k_x, 0)$$ FEM

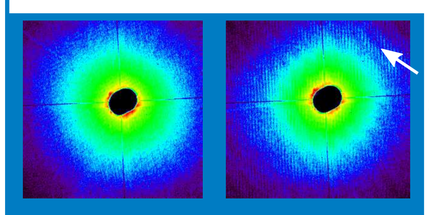
[3]

CCD pictures from light scattered off an unstructured ML mirror

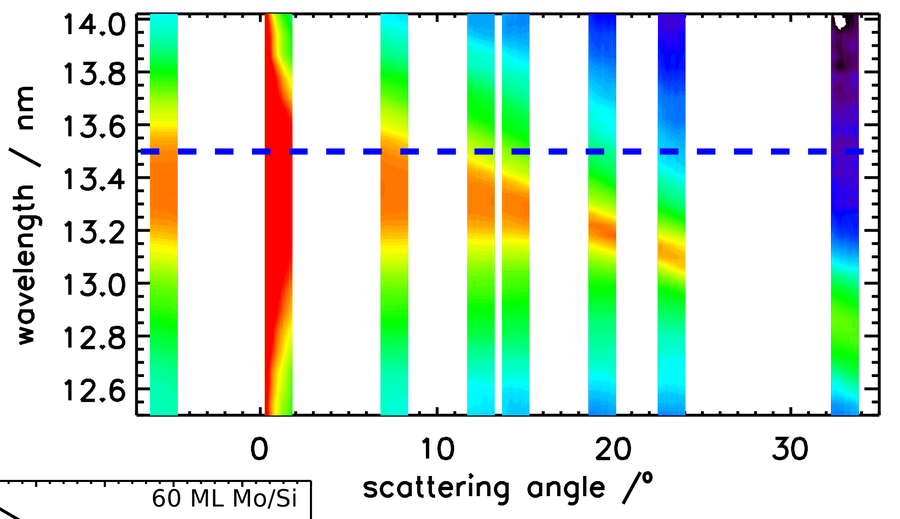


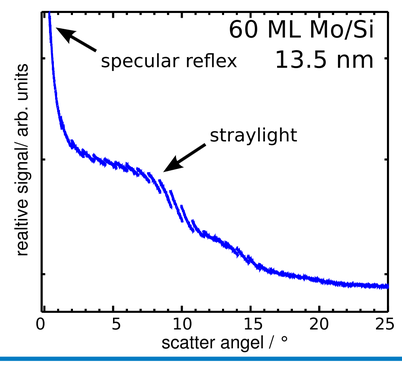
large beamstop | small beamstop | specular beam





local fine structure





CCD measurements around the specular reflection of a EUV ML-Mirror (13.5 nm)

[1] C. Brönnimann et al., J. Synchrotron Radiat., 13 (2006) 120-130 [2] J. Wernecke et al., Rev. Sci. Instrum. (2012) [3] A. Kato et al., Applied Optics Vol. 51, Iss. 27, pp. 6457–6464 (2012)

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